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Forests, Fire, and Faucets: What We Are Learning About Lingering Water Quality Effects of High-Severity Wildfires

The 2020 Cameron Peak Fire, the largest fire in Colorado's state history, swept through high elevation stands of spruce, fir, and lodgepole pine along the Continental Divide. Cameron Peak burned a great swath of the upper watershed of the Cache la Poudre River, which supplies drinking and industrial water to much of the northern Colorado Front Range, including the cities of Fort Collins and Greeley. The fire also burned in and around six high-elevation storage reservoirs and other critical water supply infrastructure.

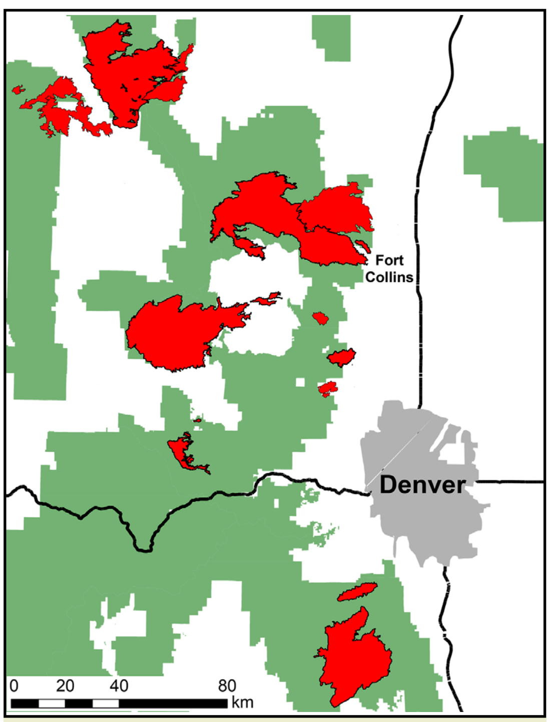
Eight years earlier, the 2012 High Park Fire scorched more than 85,000 acres of forest, consisting primarily of ponderosa pine, in lower-elevation portions of the same watershed. Those forests served important watershed functions, including stabilizing soils and reducing runoff. In the year after the High Park Fire, extreme erosion, runoff, and debris flows severely degraded water quality in the main stem and tributaries of the Poudre watershed. Ash and blackened soil spilled

Photo taken in 2018 of the burn scar from Colorado's 2002 Hayman Fire. Photo courtesy of Oscar Rhoades.

into the river during rain storms, turning its normally crystal-clear waters black. The muddy river even threatened to clog the intake pipes leading to the water treatment plant for the city of Fort Collins, forcing the city to switch to an alternative water supply.

Across the Intermountain West, snowpack in forested headwaters is the primary, if not sole, water supply source for many communities. And the forests themselves play a crucial role in maintaining the snowpack and helping to deliver high-quality water to downstream communities. High-severity wildfires are threatening water supplies, like those in Colorado, in some longer term and concerning ways.

"Forested watersheds are actually part of the water infrastructure in the West, just like the pipes that deliver water to your house," said Frank McCormick, the science program manager for the Rocky Mountain Research Station Air, Water, and Aquatic Environments program. "But they are only a healthy part of that system when they are intact."



Perimeters of major wildfires affecting watersheds on the Front Range of Colorado since 1996.

Municipal water systems along the Colorado Front Range are designed around the assumption of high-quality water delivery from forested headwaters to the system intake. But large, high-severity wildfires can disrupt the water supply system by damaging infrastructure, increasing sedimentation in streams and reservoirs, and changing how watersheds retain and release nutrients, resulting in lower water quality and higher water treatment costs.

Results from a series of long-term studies conducted by Rocky Mountain Research Station scientists and collaborators of the watershed impacts of the Colorado 2002 Hayman Fire, show that the watershed effects of high-severity fires, such as elevated nutrient and carbon export, may linger for decades. They also suggest that more targeted approaches to post-fire

SUMMARY

Across the Intermountain West, snowpack in forested headwaters is the primary, if not sole, water supply source for many communities. And the forests themselves play a crucial role in maintaining the snowpack and helping to deliver high-quality water to downstream communities.

A series of large, high-severity wildfires along the Colorado Front Range over the past few decades has had broad effects on forested watersheds, with serious consequences for water quality, aquatic habitats, and ecosystem resilience.

RMRS researchers have partnered with managers on the Pike-San Isabel National Forest to study post-fire stream nutrients, carbon, and sediments after the 2002 Hayman Fire, and other high-severity fires in forest headwaters of the Front Range. Long-term research in the Hayman Fire burn area shows that stream nitrogen and carbon can remain elevated for decades after severe wildfires because of the lack of vegetation recovery and reduced nutrient retention within burned watersheds.

One of the main challenges is that in the initial period after the fires, the threats from debris flows and erosion are so overwhelming that it's difficult for managers to prioritize long-term watershed recovery during the short window when rehabilitation resources are available.

The long-term research and monitoring in the Hayman burned area suggests that planting in riparian areas and along stream corridors has potential to increase nutrient retention and reverse long-term water quality concerns while benefiting many other ecosystem functions and conditions.

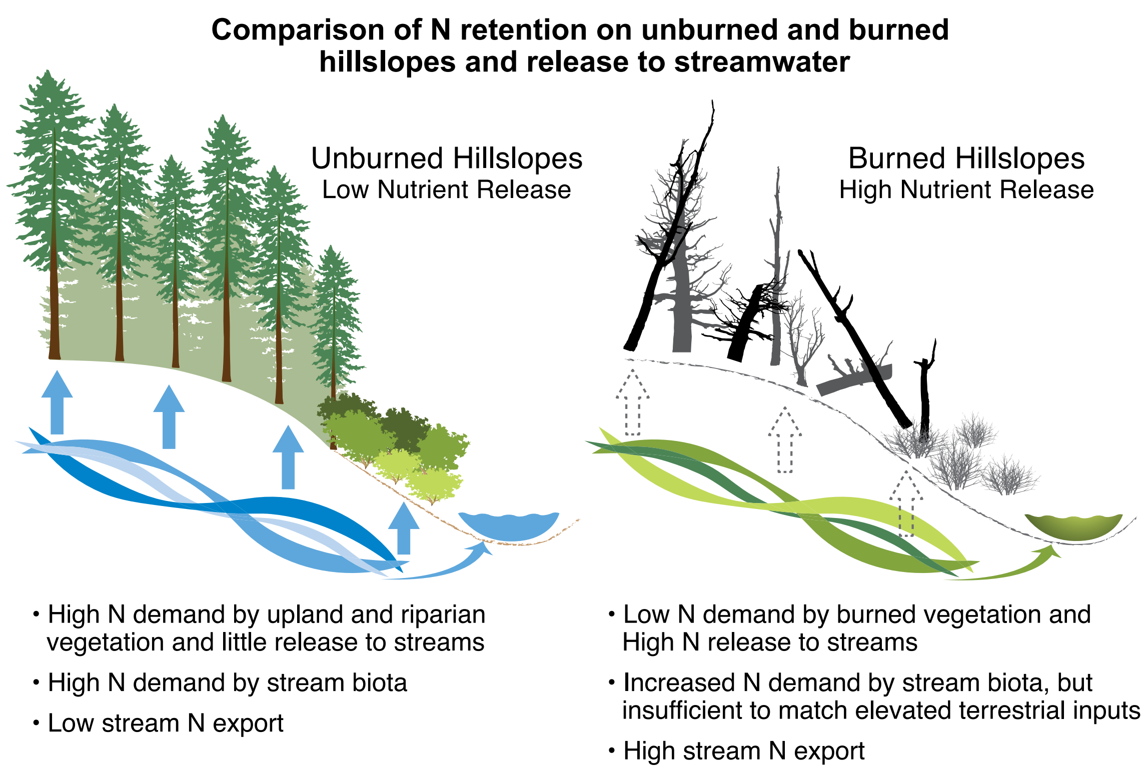
watershed rehabilitation and revegetation may be needed to replace watershed processes that regulate clean water supply and provide critical aquatic habitat.

The Hayman Fire Legacy

For close to two decades, Chuck Rhoades, a Rocky Mountain Research Station researcher, and his collaborators have been studying the effects of the Hayman Fire on the South Platte River watershed. The South Platte is a key part of the water supply network for the city of Denver. At more than 138,000 acres, the Hayman was the largest fire in Colorado history before three 2020 fires eclipsed it, including the massive 208,663-acre Cameron Peak Fire and the 193,812-acre East Troublesome Fire. Overall, 35 percent of the Hayman burned at high severity, leaving vast treeless patches on the Pike-San Isabel National Forest southwest of Denver. In many portions of the burn area, trees and forests haven't returned almost two decades later, and fire effects on downstream water quality continue now.

"One of the key messages from this work is that the slow recovery of vegetation means long-term

Riparian area within the Hayman Fire burn scar (2018). Photo courtesy of Oscar Rhoades.



watershed responses" Rhoades said. "It also means we have to think about what these even larger high-intensity fires are going to mean for watershed recovery, especially in these areas that are critical for drinking water, agricultural water, and industrial water suppliers. I'd say it's an unavoidable wake-up call."

"One of the key messages from this work is that the slow recovery of vegetation means long-term watershed responses"

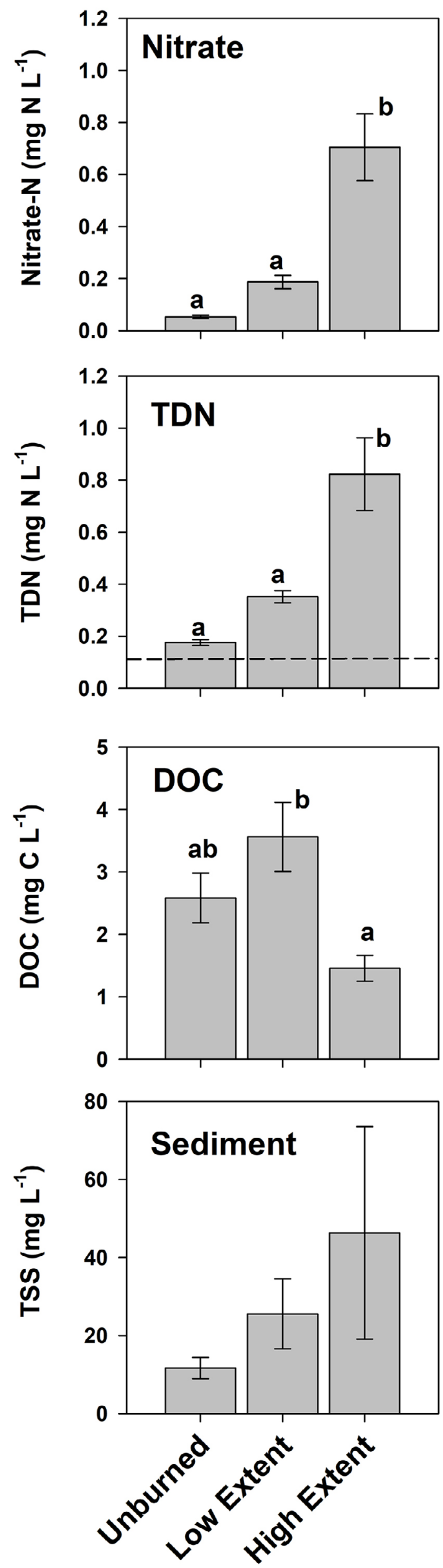
A network of stream monitoring sites established by Rocky Mountain Research Station scientists and Forest Service managers prior to the Hayman Fire provided the core of the stream sampling network. This important baseline data allowed the researchers to evaluate short- and long-term effects of the fire on stream nutrients, sediment, and other water quality indicators.

Predictably, the most severely burned streams in the watershed saw the greatest changes in post-fire water quality. In the first five years after the fire, nitrogen levels were highest in streams flowing through portions of watershed burned by high-severity fires. These fires consume nearly all the vegetation, including trees that take up large amounts of nutrients from the soil. Without this uptake, the resulting surplus of soil nutrients then leaches downslope to the streams.

Allison Rhea, a student at Colorado State University, worked with Rhoades on post-Hayman nutrient dynamics in the South Platte watershed project for her graduate research. Rhea views excess stream nitrogen as a signal of problems in ecosystem health since nitrogen is typically a limiting nutrient in forest headwaters. Normally, there's not enough nitrogen to fill the demand from trees and other vegetation.

"The slow post-fire forest recovery means lower plant nutrient demand and we're seeing that translate into greater downstream nitrogen losses," Rhea said. "There's not enough vegetation to take up the nitrogen, and the excess is exported."

Much of the excess nitrogen is transported downstream where it can cause algal blooms that can lead to taste and odor issues in the water treatment process. When blue-green algae (cyanobacteria) blooms occur, they can release



Mean concentrations of nitrate, total dissolved nitrogen (TDN), dissolved organic carbon (DOC), and total suspended sediment (TSS) from catchments burned by the 2002 Hayman Fire and nearby, unburned catchments. Burn Extent classes as follows: High Extent: > 60% burned, Low Extent: 30-60% burned, and unburned. Letters denote means that differ at α < 0.05. The dashed line on the TDN panel denotes the U.S. EPA-proposed TDN threshold concentrations for least-impaired reference streams in the Western Forest Region.

This 2019 photo taken near Cheesman Reservoir documents the sparse forest recovery since the 2002 Hayman Fire. USDA Forest Service photo by Thomas Timberlake

cyanotoxins that can be harmful to humans, domestic animals and livestock, and wildlife.

In another Hayman study led by Alex Chow of Clemson University, the researchers found elevated levels of dissolved organic carbon (DOC) in streams more than a decade after the fire. DOC enters streams from vegetation that is burned and transformed into ash and charcoal, which can eventually end up in streams. When DOC reaches water treatment systems, it can react with the chlorine used to disinfect water and form disinfection byproducts, or DBPs, which can be harmful in drinking water. In fact, the U.S. Environmental Protection Agency regulates the level of permissible DBP (by products). The highest post-fire DOC concentrations occurred in moderately burned drainages.

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Rhoades explains that the carbon response differs from nitrogen, which typically increases in relation to wildfire extent and severity.

"If the wildfire burns at high severity and consumes most of the vegetation, most of the carbon is lost as CO2, so there's little left to leach into streams," Rhoades said. "But in a moderate-severity fire, you have more charred materials sticking around and vegetation that didn't die that produces carbon that is released into the watershed."

It's All Downhill from Here

While treatment costs for nitrogen and carbon are a concern, sedimentation is by far the biggest threat to the water delivery infrastructure in the first few years after a fire.

In unburned forests, ground cover and vegetation stabilize soils and prevent erosion by intercepting rainfall and promoting infiltration. Fires remove these protective layers, increasing runoff across bare mineral soils. Fires can create hydrophobic layers that repel water and reduce infiltration. Rainstorms can then mobilize and erode mineral soils. Increased runoff means more volume of water in streams, leading to bank erosion and channel restructuring, all of which combine to further erosion and sedimentation. Downstream, higher sediment loads can fill reservoirs

From Forests to Faucets

To help protect forest health in critical watersheds along the Colorado Front Range, Denver Water has partnered with the USDA Forest Service, Colorado State Forest Service, and the Natural Resources Conservation Service in an ongoing effort called "From Forests to Faucets."

The partnership was formed in response to the costly Buffalo Creek and Hayman wildfires of 1996 and 2002, respectively. After the fires, Denver Water, the utility supplying clean water to users in the Denver metro area spent tens of millions to repair infrastructure, remove sediment, and restore land around key drainages that flow into Strontia Springs and Cheesman reservoirs, which play critical roles in the water supply for the Denver metro area.

The aim of the partnership is to restore watersheds through large-scale planting in burned areas as well as improving watershed resilience through proactive forest fuel treatments, using prescribed fire and thinning, to prevent or mitigate the effects of large-scale fires. Since 2010, From Forests to Faucets funding has paid for forest treatments across more than 100,000 acres, including planting more than a million new trees in burned areas within priority watersheds.

"We are trying to proactively prevent sediment from getting into the reservoirs through targeted riparian plantings and other watershed management techniques," said Christina Burri, a watershed scientist with Denver Water. "Even if we only prevent 5 percent of sediment from getting into the reservoir, we still get a return on investment because of how expensive it is to dredge."

From Forest to Faucets is also working to mitigate risk of future high-severity fire. Fuel reduction treatments prioritize "zones of concern," which are essentially "at-risk" watersheds identified through an assessment that analyzed and ranked wildfire hazards, flooding and debris risks, soil erodibility, and water uses.

More resources: From Forests to Faucets Story Map

Before and after photos of a 98-acre treatment near Dillon Reservoir under the From Forests to Faucets program. Photo courtesy of Denver Water.

used for drinking water and disrupt the water treatment process.

The 1996 Buffalo Creek Fire is a prime example of how sediment can disrupt water storage after a fire. The intense fire scorched 12,000 acres of forest in the South Platte River watershed. Less than two months after the fire, flash flooding sent an estimated 160,000 cubic yards of debris and sediment—equal to 17,000 dump truck loads—into Strontia Springs Reservoir. Similar flash flooding occurred six years later when the Hayman Fire burned 138,000 acres around Cheesman Reservoir. Denver Water spent more than $28 million to repair infrastructure, remove sediment, and restore forests in the Buffalo Creek and Hayman burn areas. This work was not immediately after the fire; it happened over a number of years. However, Denver Water still is incurring recovery costs today.

Christina Burri, a watershed scientist with Denver Water, said that sedimentation related to the Buffalo Creek and Hayman fires is still a significant problem for the reservoirs in the South Platte watershed.

“Until the vegetation recovers or there is some type of ground cover, erosion is going to continue to happen,” Burri said.

Short-Term Threats vs. Long-Term Recovery

Recovery of ponderosa pine forests in the Hayman burn area has been slow, with tree regeneration only occurring near the edges of unburned forests. Marin Chambers, a researcher with the Colorado Forest Restoration Institute at Colorado State University, began her career studying post-fire tree regeneration in severely burned areas, including Hayman. Some of her work now focuses on watershed stakeholders, such as water providers, and what they want out of their forested landscapes.

Sedimentation after the 1996 Buffalo Creek Fire. Photo courtesy of Denver Water.

“If we know that water quality is directly linked to the vegetation on the landscape, then planting trees and other vegetation in riparian stream corridors, drainages, and possibly upland areas is really the direction we need to be headed,” Chambers said.

Thomas Timberlake, a cooperative forestry program assistant for the USDA Forest Service Rocky Mountain Region, believes that the findings of the Hayman studies, showing the long-term water quality effects of severe fires, can help identify and prioritize riparian areas and other important watershed areas for post-fire restoration, specifically tree planting, to reverse the long-term watershed changes.

“How do you promote replanting in a way that’s focused first and foremost on watershed function? Focusing on riparian areas for reforestation work could be a more cost-effective way to invest limited planting dollars since trees might have may have a better chance of surviving, given that they might be a little wetter in the future,” Timberlake said. “And having vegetation in place in riparian areas might have more long-term, larger-scale benefits for overall watershed function.”

"These fires are changing what the baseline looks like, and that really changes the frame and urgency around investing in restoration and fire mitigation to prevent these sorts of outcomes."

It is a challenge to think about long-term watershed recovery in the aftermath of severe wildfire when attention is on damaging hillslope erosion and debris flow, but Jen Kovecses, the former executive director of the Coalition for the Poudre River Watershed, said that the Hayman Fire water quality research underscores the urgency to ramp up watershed recovery efforts in the early years post-fire to stem the longer-term chronic changes to water quality.

"These fires are changing what the baseline looks like, and that really changes the frame and urgency around investing in restoration and fire mitigation to prevent these sorts of outcomes," Kovecses said.

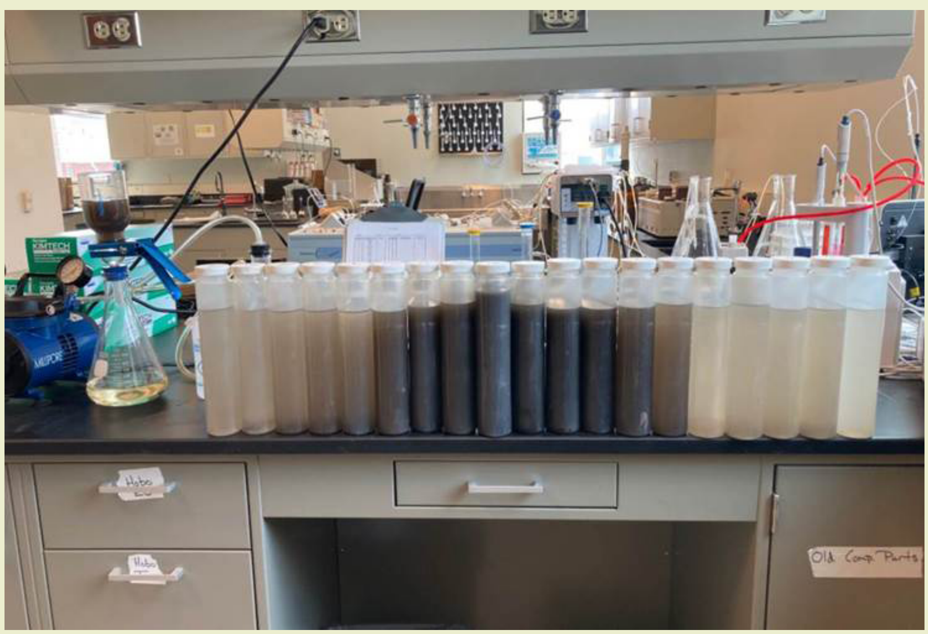
Kovecses said the Hayman Fire research, as well as the challenge of controlling the water quality effects after the High Park Fire, highlighted the need to shift gears and think about wildfire risk mitigation at a much larger scale to prevent future

Back at the Lab

The Fort Collins Biogeochemistry Laboratory is a research facility operated by the Air, Water, and Aquatic Environments (AWAE) program at the Rocky Mountain Research Station. The lab supports the research of scientists at the station and other government agencies, academic institutions, and private research entities and monitoring needs of land management partners by analyzing soil, vegetation, and water samples. Equipped with cutting-edge instrumentation and experienced staff members, the biogeochemistry lab provides a wide range of analytical abilities for research and other applications pertaining to post-fire studies, and a range of other studies related to environmental chemistry.

"Our lab's focus is high precision chemistry and nutrient analysis of soil and water samples," said Tim Fegel, manager of the biogeochemistry lab. "The instruments and methods we use are designed to address the monitoring and research needs of our scientists and our research and management collaborators—this work relates to water quality, soil productivity, soil and aquatic restoration, and long-term changes after disturbances like wildfire and bark beetle outbreaks." Current monitoring and research collaborations include the USDA Forest Service Air Resource Management Program–Wilderness Lakes and Wild and Scenic River Monitoring, Fraser Experimental Forest, Glacier Lakes and Loch Vale watershed monitoring, and various CSU and CU biogeochemical researchers.

The biogeochemistry lab offers water sampling analysis, with an analytical package customized for specific needs. For more information visit the webpage: https://www.fs.usda.gov/rmrs/research-labs/fort-collins-biogeochemistry-laboratory or call 970-498-1017.



A series of water samples collected every 15 minutes following a large monsoon rainstorm in a watershed affected by the 2020 Cameron Peak Fire and ready for analysis in the RMRS Water Lab. USDA photo courtesy of Tim Fegel.

large wildfires. That realization has led to action on the ground, including a large thinning and prescribed fire treatment program on the Arapaho and Roosevelt National Forests.

"We need to start thinking at a bigger spatial scale for the treatments we are trying to put on the ground for watershed restoration and wildfire risk mitigation—if we want them to make a difference," said Kovecses. "Because that's the scale that these ecosystems operate on and that's the scale of the fires we're experiencing."

After two decades of experience responding to the water quality and watershed recovery challenges of high-severity fires on the Colorado Front Range, researchers and managers now have a much deeper understanding of the persistent and chronic long-term water quality changes that can occur in forested watersheds. That knowledge is informing the response to the 2020 fires and prompting new landscape-scale approaches to wildfire mitigation.

Rhoades said: "The size, severity and location of the 2020 fires highlighted concerns about watershed responses and long-term clean water supply for aquatic habitat and residential, agricultural and industrial uses. It's been an important wake up call."

Management Implications

- Excess nitrogen in streams can feed downstream algal blooms in reservoirs that can cause water color and odor issues in the water treatment process, or form cyanotoxins and cyanobacteria in reservoirs that can be harmful to humans.
- Dissolved organic carbon in streams can react with the chlorine used to disinfect water in treatment systems and form byproducts, which can be harmful in drinking water.
- The existing network of stream monitoring sites can help target specific locations where strategic streamside plantings have potential to reverse post-fire water quality concerns by increasing nutrient retention within vegetation.
- Post-fire revegetation along stream corridors and lower hillslopes has potential to increase nutrient retention and reverse long-term water quality concerns while benefiting numerous other ecosystem functions and conditions.

Key Findings

- The most severely burned streams in the Hayman burn area saw the greatest changes in post-fire water quality.
- Long-term research shows that stream nitrogen and dissolved organic carbon can remain elevated for decades after severe wildfires.
- Nutrient enrichment in streams is a direct response to slow vegetation recovery and reduced nutrient retention within burned watersheds.

Further Reading

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Scientists and Manager Profiles

Chuck Rhoades is a research biogeochemist at the Rocky Mountain Research Station in Fort Collins, CO. He studies linkages between terrestrial and aquatic ecosystems in managed and unmanaged areas. Connect with Chuck at https:// www.fs.usda.gov/rmrs/people/crhoades.

Frank McCormick is a research program manager and ecologist at the Rocky Mountain Research Station in Fort Collins, CO. He studies ecological processes in streams. Connect with Frank at https://www.fs.usda.gov/rmrs/people/fmccormick.

Scientists and Manager Profiles

Tim Fegel is the manager of the biogeochemistry laboratory at the Rocky Mountain Research Station in Fort Collins, CO. His research focuses on how land cover changes affect the chemistry and productivity of watersheds. Connect with Tim at https://www.fs.usda.gov/rmrs/people/tfegel.

Marin Chambers is a research associate and program manager with the Colorado Forest Restoration Institute. Her primary interests are disturbance and restoration ecology. Marin's recent research examines forest regeneration and resilience in post-fire landscapes in the Southern Rockies region.

Allison Rhea is a Ph.D. student in watershed science and a research associate with the Colorado Forest Restoration Institute. Her dissertation research focuses on post-fire watershed nutrient cycling and the nexus between burned landscapes and water quality.

Christina Burri is a watershed scientist at Denver Water, leading watershed management and planning efforts, including forest health investments. As part of this effort, she manages the From Forests to Faucets partnership. Christina holds a degree in environmental sciences, with an emphasis on water quality and public health.

Jen Kovecses grew up playing in lakes and streams in Canada, building a life-long interest in aquatic ecosystems and conservation. She completed a Bachelor of Science in biology and a Master of Science in aquatic ecology at McGill University. She was the executive director for Coalition for the Poudre River Watershed for more than 7 years. She is currently the program director for the Salazar Center.

Thomas Timberlake is a climate change and science coordinator at the Western Wildland Environmental Threat Assessment Center at the USDA Forest Service's Pacific Northwest Research Station. He holds a Ph.D. in forest sciences from Colorado State University.

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